THE TOXIC ACTION OF ORGANIC COMPOUNDS AS MODIFIED BY FERTILIZER SALTS[1]

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(WITH FIVE FIGURES)

In a former paper[2] the results obtained with dihydroxystearic acid, a crystalline organic compound isolated from a number of unproductive soils, was presented. The results obtained with this organic soil constituent, showing its effect on growth and absorption of plant nutrients from the various culture solutions containing a wide range of fertilizer composition, showed the desirability of obtaining further information concerning the behavior of other organic bodies known to be harmful to plants.

In the present paper some of the results obtained in experiments with toxic organic substances and the restraining influence on their toxicity by fertilizer mixtures of different composition will be given. The compounds studied, though not actually isolated from soil, are common constituents of plant débris, or result from this through changes, and so become, at least temporarily, components of the soil. The effects of a large number of such compounds on plant growth was given in an earlier paper.[3] Of these compounds, cumarin was selected for the continuation of these researches because it was quite harmful even in minute amounts, a few parts per million of solution having a noticeable effect on plant growth, and because it was a common constituent of a number of plants the remains of which get into the soil.

The earlier results were obtained in solutions of the cumarin in distilled water. The present investigation concerns itself with the effect of cumarin in the presence of nutrient salts as well, the

[1] Published by permission of the Secretary of Agriculture, from the Laboratory of Fertility Investigations.

[2] SCHREINER, O., and SKINNER, J. J., Some effects of a harmful organic soil constituent. BOT. GAZ. 50:161. 1910.

[3] SCHREINER, O., and REED, H. S., The toxic action of certain organic plant constituents. BOT. GAZ. 45:73, 271. 1908.

essential constituents of these being present to the extent of 80 ppm., but the composition varies. The number of culture solutions of the fertilizer salts used was 66, this being the number requisite to obtain every possible ratio of P_2O_5, NH_3, and K_2O, in 10 per cent stages. The system employed, as well as all details of preparation, was the same as already described in the similar investigation with dihydroxystearic acid already mentioned.

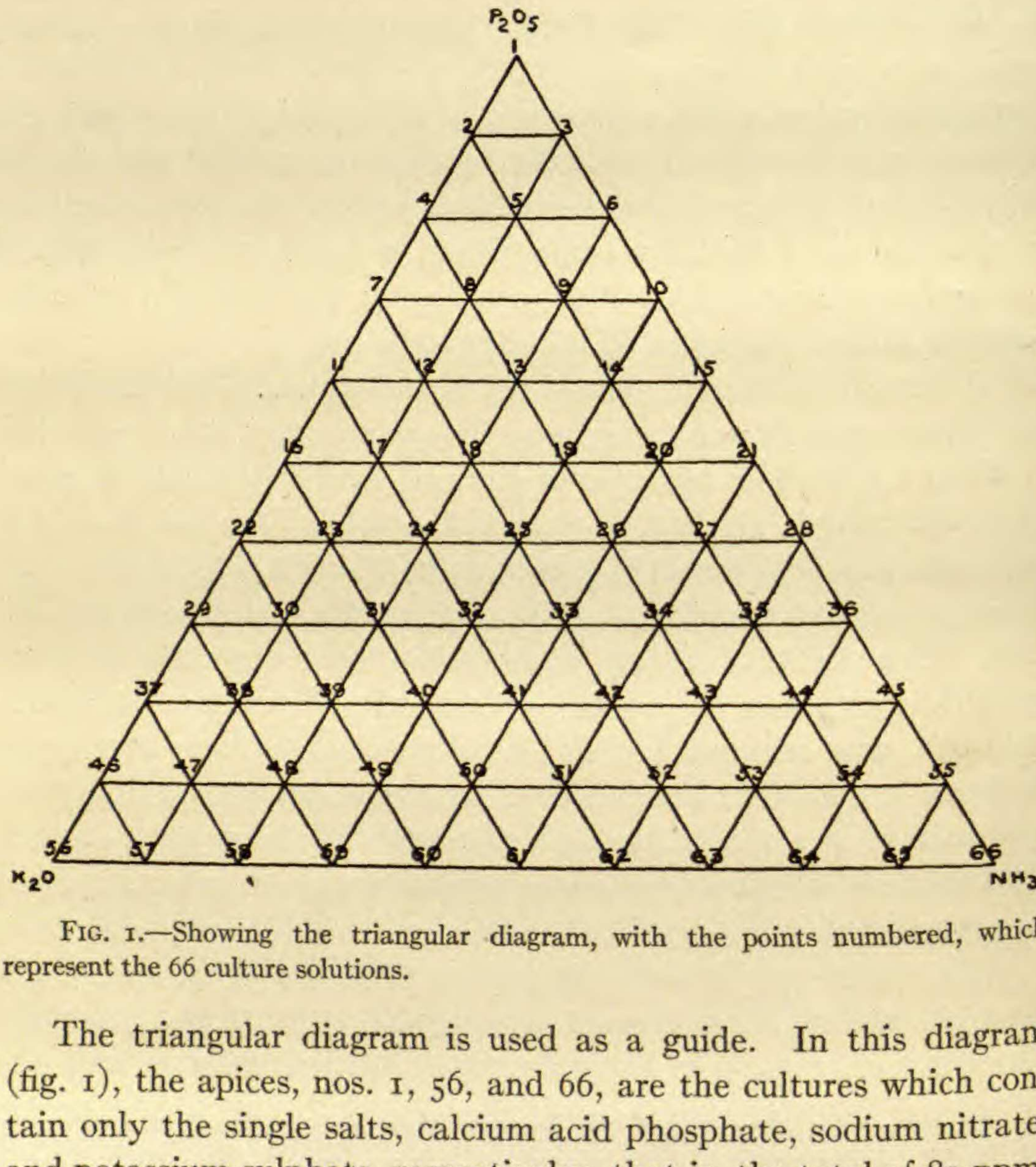

FIG. 1.—Showing the triangular diagram, with the points numbered, which represent the 66 culture solutions.

The triangular diagram is used as a guide. In this diagram (fig. 1), the apices, nos. 1, 56, and 66, are the cultures which contain only the single salts, calcium acid phosphate, sodium nitrate, and potassium sulphate, respectively; that is, the total of 80 ppm. contains 100 per cent of P_2O_5, NH_3, or K_2O, respectively. The line of cultures between 1 and 66 contains mixtures of P_2O_5 and NH_3 in 10 per cent differences; the line of cultures between 1 and 56 contains mixtures of P_2O_5 and K_2O in 10 per cent differences; the line of cultures between 56 and 66 contains mixtures of K_2O and NH_3. The cultures in the interior of the triangle contain mixtures of all constituents, differing in 10 per cent stages one from the other, the composition depending upon its position in the triangle; those nearer the P_2O_5 apex consisting chiefly of phosphate fertilizer, those nearer the NH_3 apex chiefly of nitrate fertilizer, and those nearer to the K_2O apex chiefly of potash fertilizer. For a more detailed explanation of the scheme and principles involved, the reader is referred to an earlier paper.[4]

Two sets of these 66 culture solutions were prepared, one of them containing in every culture 10 ppm. of cumarin. The total concentration of the nutrient elements $P_2O_5+NH_3+K_2O$ was in all cases 80 ppm. The culture solutions were contained in wide-mouth bottles and 10 wheat seedlings grown in each culture after the manner described in the paper cited. The culture solutions were changed every three days, four such changes being made in each experiment. The culture solutions were analyzed immediately after each change for nitrates, but the phosphate and potassium were determined on a composite of the four changes. The green weight of the plants was determined at the termination of the experiment. The first experiment with cumarin was set up on December 9 and discontinued December 21.

The effect of even so low a concentration as 10 ppm. of cumarin was strikingly noticeable in the difference between the plants growing in the two sets of cultures. The appearance of plants growing in solutions containing cumarin is very characteristic and totally different from the effect on wheat of any other toxic compound worked with in this laboratory. The leaves are shorter and broader than is normal for wheat, and only the first leaves are usually unfolded, the other leaves remaining wholly or partially within the swollen sheath; such leaves as do break forth are usually distorted and curled or twisted. The appearance is so characteristic that the investigator can pick out the cumarin-affected plants from those affected by any other toxic body in the same experiment by

[4] SCHREINER, O., and SKINNER, J. J., Ratio of phosphate, nitrate, and potassium on absorption and growth. BOT. GAZ. **50**:1. 1910.

a mere glance. This characteristic behavior of cumarin-affected plants becomes, therefore, in addition to the usual criteria, an indicator of the degree of its harmfulness in the cultures of different composition in this experiment. In addition to its effect on the tops, as just described, there was a general inhibition of root growth, as is the case with many other substances, notably the dihydroxystearic acid already described.

The effect of the cumarin was to depress the green weight of the plants from 100 to 88 as an average in this experiment, although it was obvious from the appearance of the cultures that its effect was far from uniform in all of the cultures, and this is the most interesting feature of the experiment.

It will be recalled that with dihydroxystearic acid the more normal growth was observed in the nitrogen end of the triangle, but when the cumarin cultures were set out in this triangular form according to the composition of the culture solutions, it became at once apparent that the result with the cumarin was not in harmony with the observation so repeatedly made with the dihydroxystearic acid. It was clear that the cumarin had an entirely different effect in the different culture solutions from that observed in the case of dihydroxystearic acid, which had responded most in the fertilizer combinations high in nitrate. With the cumarin the growth was more nearly normal in the fertilizer combinations high in phosphate. In comparing the cultures, those of like composition only are compared in the cumarin and in the normal sets.

This influence of the phosphate on the harmful effect of the cumarin is perhaps most strikingly shown in the difference between the plants growing in the culture solution containing no phosphate whatever, namely along the line 56 to 66 in fig. 1, and the line of cultures immediately above this, containing 10 per cent phosphate in the fertilizer mixture. Where phosphate is entirely absent, the effect of the cumarin is most marked. Above this line the harmful effect of the cumarin steadily decreases, and in the upper part of the triangle disappears altogether, so far as the eye can detect this in the appearance of the plants in the normal and cumarin set.

The effect of the phosphate in overcoming the harmful action of the cumarin is shown in the green weight of the plants taken at the termination of the experiment. In table I is given the green weight of the series of cultures containing the same amount of phosphate; that is, the series along any one of the horizontal lines in fig. 1.

TABLE I

SHOWING THE INFLUENCE OF PHOSPHATE IN OVERCOMING THE HARMFUL EFFECT OF CUMARIN

Percentage of P_2O_5 in fertilizer mixtures	Parts per million of P_2O_5 in original solutions	Number of cultures included	Green weight of cultures		
			Without cumarin	With cumarin	Relative (without cumarin = 100)
0	0	11	21.773	15.370	70
10	8	10	22.408	18.835	84
20	16	9	20.339	17.140	84
30	24	8	17.143	15.350	90
40	32	7	15.008	14.085	94
50	40	6	11.188	11.150	100
60	48	5	9.113	9.005	99
70	56	4	6.915	6.485	94
80	64	3	4.171	4.330	104
90	72	2	2.388	2.530	106
100	80	1	0.932	0.955	102

The last column of the table gives the relative growth between the two sets of cultures, with and without cumarin. It will be seen from the last column of the table that in those cultures in which no phosphate was present the depression in growth caused by cumarin was greatest, being reduced to 70 per cent of the normal, and that the introduction of 8 ppm. of phosphate caused the growth to rise to 84 per cent of the normal. On further increasing the phosphate content to 16, 24, 32, and 40 ppm., the green weight rose to 84, 90, 94, and 100 per cent of the normal, respectively. From this point on the growth is practically as good in the cumarin set as in the normal control set, thus showing that, on the whole, the fertilizer combinations high in phosphate were practically able to overcome the harmful influence of the toxic cumarin.

The lessened toxicity of cumarin in solutions high in phosphate is also shown when the results of the experiment are grouped in such a way as to obtain all cultures containing 50 per cent and over of any one of the three constituents, P_2O_5, NH_3, and K_2O, as was done in the case of the dihydroxystearic acid experiment. This is accomplished by taking the cultures contained in the smaller triangles formed at each angle of the larger one shown in fig. 1; that is, the cultures contained within the triangles 1, 16, 21; 21, 61, 66; and 16, 56, 61, respectively. The sum of the green weights in these respective triangles is shown in fig. 2 for the normal and the cumarin sets, together with the relative growth. The phosphate

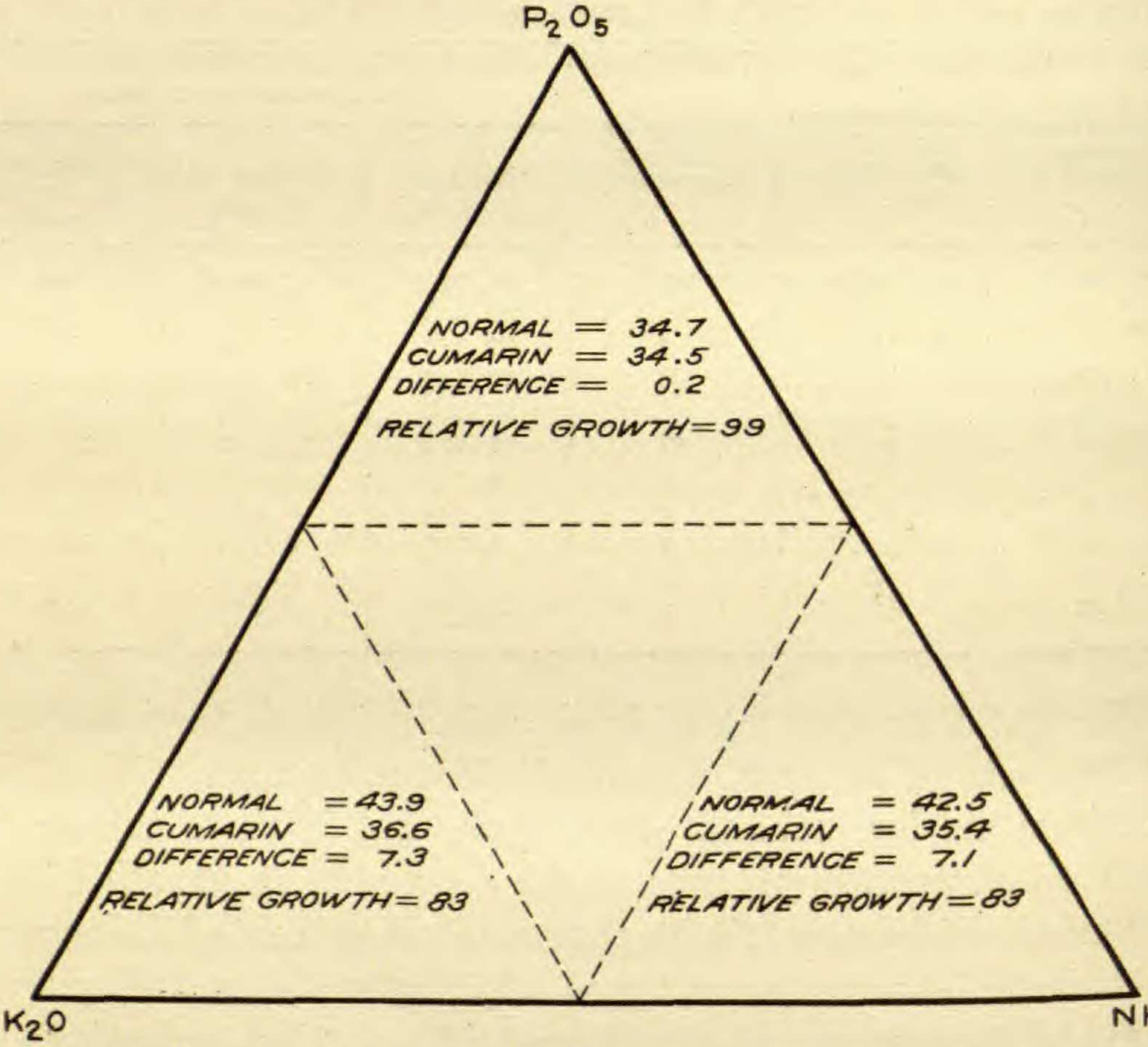

FIG. 2.—Showing the relative growth of normal and cumarin cultures in solutions high in phosphate, nitrate, or potash, respectively.

end shows that the growth in the cumarin set was nearly normal 99 per cent, whereas the potash and the nitrogen end showed a growth only 83 per cent of the normal.

A second set of experiments with cumarin was made and was in all respects conducted as in the first experiment. This grew from January 12 to January 24.

The cumarin-affected plants showed the same characteristic stunting of the leaves as in the former experiment, and, moreover, again showed strikingly the influence of phosphate in overcoming this effect, the general appearance of the entire triangle of cultures being similar to that already described. The effect of the cumarin was to depress the green weight from 100 to 75 in this second experiment, this being the average depression for all the cultures in the set. Here, as in the first experiment, the toxicity of the cumarin was lessened most in the solutions high in phosphate, being 85 per cent of the normal as compared with 74 and 70 per cent in the cultures high in nitrate and potash, respectively.

The line of cultures containing no phosphate whatsoever again showed the greatest effect of the cumarin; this harmful influence becoming less and less until complete recovery of the plants is noticed in the cultures containing higher amounts of phosphate. The total absence of phosphate showed a depressed growth equal to 62 per cent of the normal; this rises to 70 per cent on the addition of 8 ppm., and to 76 per cent on the addition of 16 ppm., and so on upward, somewhat irregularly but definitely, until in the higher concentration of phosphate the effect of the cumarin is lost entirely.

The foregoing experiments show clearly the influence of cumarin on growth and the effect of phosphate in counteracting the harmful influence of the cumarin. There remains to be considered the influence of the cumarin on the concentration of the solution during the growth of the plant.

Mention has already been made of the fact that the concentration differences produced by the growth of the plants in the various cultures was determined by making an analysis for nitrate at the termination of every three-day change, and of the phosphate and potassium on a composite of the solutions from the four changes. It is thus possible to compare the results obtained under the so-called normal conditions without the cumarin and under the conditions where 10 ppm. of cumarin were present in the solution. The 36 cultures comprising the fertilizer combinations in which all three fertilizer elements are present were consistently analyzed and these only are here considered.

The amount of total $P_2O_5+NH_3+K_2O$ removed from solution by the growing plants in the total number of 36 cultures was 1379 milligrams under the normal conditions and 1272 milligrams in the cumarin set. In table II are given the results for the P_2O_5, NH_3, and K_2O, separately, under the normal conditions and in the cumarin set.

TABLE II

TOTAL MILLIGRAMS OF P_2O_5, NH_3, AND K_2O REMOVED FROM THE 36 CULTURE SOLUTIONS CONTAINING ALL THREE OF THESE INGREDIENTS

	Total absorption in milligrams		Relative	Percentage of cumarin cultures above normal
	Normal	Cumarin		
P_2O_5	278.5	264.5	95	57
NH_3	482.6	415.3	86	22
K_2O	618.2	592.6	96	39

An examination of these figures discloses the fact at once that while the cumarin has decreased the absorption of these nutrient elements, it has not decreased it anywhere near the extent shown by dihydroxystearic acid in the experiment cited. The third column of figures gives the relative effect of cumarin absorption of each nutrient element, and indicates that the phosphate and potash absorptions were the more nearly normal of the three, especially the phosphate absorption if the figures in the last column are taken into account. This column gives the percentages of the individual cumarin cultures which showed an absorption equal to or greater than the corresponding culture without cumarin.

In the second experiment this effect is clearly marked, the phosphate absorption being 91 per cent of the normal, as compared with 78 and 87 for the nitrate and potash, respectively. In this experiment the total absorption of $P_2O_5+NH_3+K_2O$ was 1267 milligrams under normal conditions and 1077 milligrams with cumarin.

While these figures indicate a somewhat more normal phosphate absorption in the cumarin set than normal nitrate or normal potash absorption, the figures are, nevertheless, not decisive enough to enable one to say definitely that the antagonism of the phosphate to cumarin, as shown in the growth of the plants, is due to this cause alone. A rigid examination of the complete data does not allow us to draw this conclusion without at the same time suggesting the possibility of an external interaction between the lactone cumarin and the acid calcium phosphate. The possible solutions of the problem must be left for future investigation.

From the foregoing results it is apparent that the two toxic substances studied, dihydroxystearic acid and cumarin, show markedly different physiological properties, and are very differently influenced by fertilizer salts. Whether this is a direct action of the fertilizer on the organic body or through the medium of the plant cells, making the toxic substance and the particular fertilizer salt physiologically antagonistic, cannot be definitely stated.

The cumarin so affected the normal development of the wheat as to cause stunting of leaf growth, with abnormal appearance associated with a slightly altered absorption of plant nutrients, both as to amount and ratio, the phosphate absorption being the more normal. The fertilizer combinations high in phosphate were the most effective in antagonizing the harmful effect of cumarin.

The dihydroxystearic acid also affected normal development, causing a decrease in top growth, but no abnormal appearance, the greatest abnormality being in this case observed in the root system, which was darkened and much stunted and showed swollen root tips, often bending into fishhooks, associated with a much altered absorption of nutrient elements both as to amount and ratio, the phosphate and potassium absorption being greatly depressed, the nitrate removal or disappearance being about as under normal conditions, but relatively much greater. The fertilizer combinations high in nitrate were the most effective in overcoming the harmful effect of this soil constituent.

In view of this widely different behavior of these two toxic substances, entailing the interesting observation that they responded differently to the different fertilizer combinations, it was thought desirable to consider some results with other toxic substances. In the first place, it was interesting to see whether the result observed with dihydroxystearic acid, namely response to the nitrate, was shown by another toxic body, and thus throw a little more light on this phase of the question. For this comparison the aldehyde vanillin was selected. This was known to be toxic from former experiments, was known to be oxidized by the plant roots, and was further known to be more readily oxidized when nitrates were present,[5] and so should be a body which would behave much like dihydroxystearic acid.

In the present experiment with vanillin here recorded, the same number of cultures (66), containing all the fertilizer combinations possible in 10 per cent stages, was used as in the experiment with the dihydroxystearic acid and cumarin. The concentration of vanillin used was 50 ppm. The duration of the experiment was from March 7 to March 19. The solutions were changed every three days as in the cumarin experiment already described, but no analyses of the solutions were made in this case. The green weight, however, was recorded.

The effect of the vanillin was not so marked on the tops as on the roots, although in the regions of better growth this also was not very prominent. The general appearance of the plants resembles the effect produced by dihydroxystearic acid much more than the effect produced by cumarin under the same circumstances. The region of greatest growth appeared also, as in the case of dihydroxystearic acid, to be shifted toward the nitrogen end of the triangle. The plant growth was 84 per cent of the normal as an average of all the cultures.

For the present purpose, however, the growth in the cultures respectively high in phosphate, nitrate, or potash is of paramount interest. This grouping of the results obtained on the green weights at the termination of the experiment is shown in fig. 3. The relative growth in the cultures having 50 per cent and more of phosphate was 85 per cent of the growth without the vanillin; for the cultures mainly nitrogenous it was 88; and for the cultures mainly potassic it was 82. It will be observed that the vanillin depressed the growth least in the cultures high in nitrate, a result in harmony with previous observations on the toxicity of vanillin and in harmony with the action of dihydroxystearic acid. Both of these substances have reducing properties; that is, they are themselves readily oxidized; both have an inhibiting effect on root oxidation and on root growth generally; both are overcome by the fertilizer combinations which increase root oxidation to the greatest extent. It was consequently thought to be of interest to

[5] SCHREINER and REED, Jour. Amer. Chem. Soc. 30:85. 1908.

see what the effect of an organic compound having oxidizing properties would be on plants growing in these various fertilizer combinations. For this purpose quinone, shown to be toxic to wheat seedlings in a former research, was chosen, inasmuch as it is an oxidizing substance and therefore in strong contrast to the vanillin with its decided reducing properties. This fundamental difference

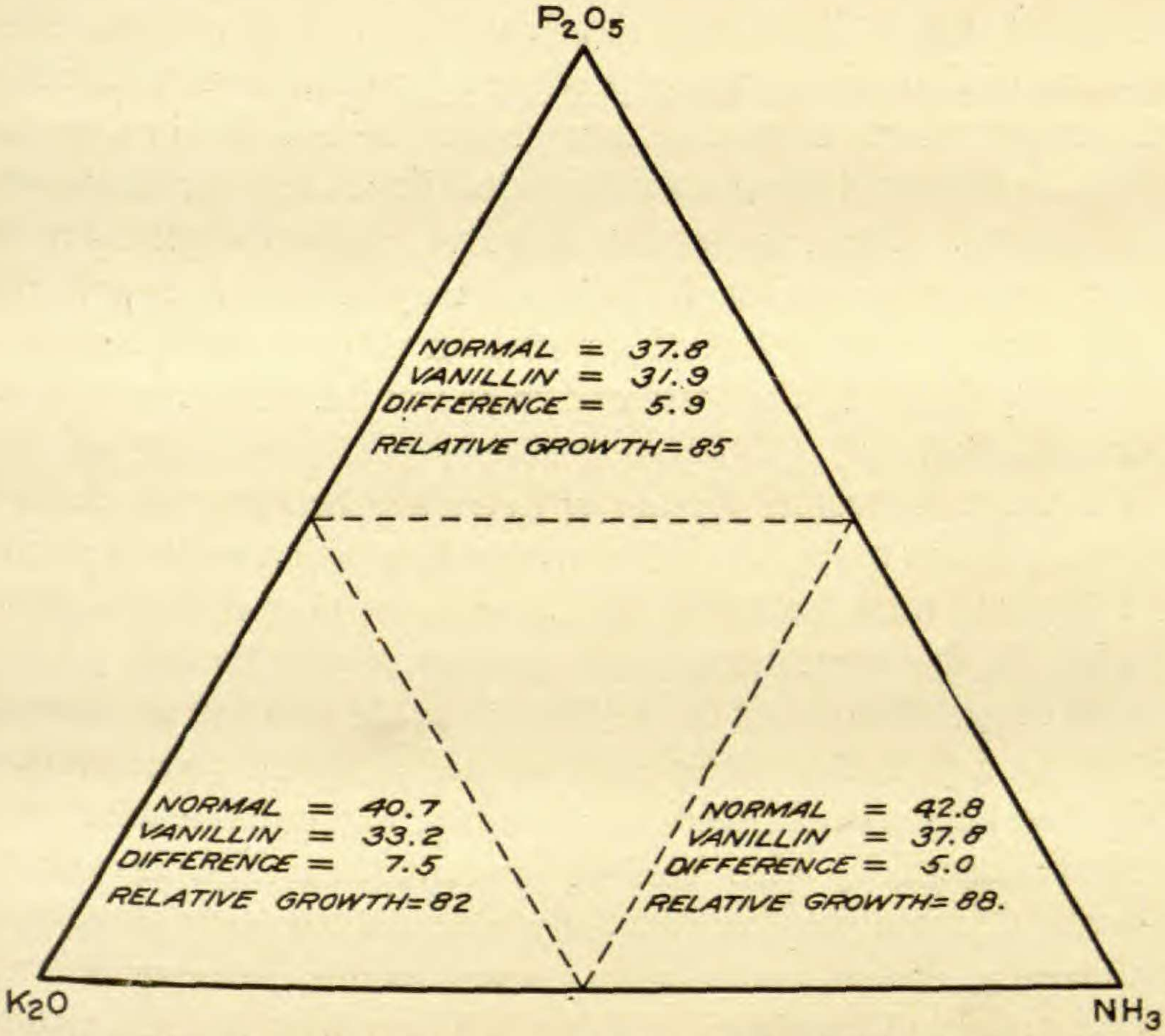

FIG. 3.—Showing the relative growth of normal and vanillin cultures in solutions high in phosphate, nitrate, or potash, respectively.

in the properties of the two compounds, it was thought, should show itself in an altered metabolism of the plants under the influence of two such widely different poisons, and the scope of the present experiment as to different fertilizer combinations should lend itself to showing such differences in metabolism or fertilizer requirement, and thus throw some light upon the behavior of crops in the field toward fertilizers under oxidizing conditions.

In the experiments with quinone the fertilizer combinations and general technique were the same as in the preceding experiments with vanillin and cumarin, the concentration of quinone being 10 ppm. No analyses of the solutions were made in this experiment. The duration of the experiment was from March 23 to April 4.

The effect of the quinone on the development of the wheat was in itself as definite, though perhaps not as characteristic, as the effect of cumarin. The effect of the latter substance was to produce short, broad, irregularly developed leaves and stunted tops; the effect of the quinone was to produce long, thin leaves, producing tall, slender plants, so that at first glance the quinone in the concentration here used appeared to have had little effect on the growth of the plants. Closer inspection, however, shows the plants to be slender and weaker, although the leaves may be fully as long as the normal leaves. The effect of quinone on plant growth, however, is definitely shown by the decreased green weight. The root growth is also affected.

The most interesting feature of difference between the normal and quinone sets of cultures, observable when both sets are arranged in triangular form according to the composition of the culture solution, is the apparent or real shifting of the greater growth toward the potassium end of the triangle in the quinone set, accompanied by a generally better relative growth in the potash angle. This observation would seem to show that the quinone effect was counterbalanced by the fertilizer combinations high in potash, whereas cumarin was undoubtedly affected by the phosphate fertilizers, as shown, and vanillin as well as dihydroxystearic acid by the mainly nitrogenous fertilizers. This effect was not anticipated, but might easily have been, inasmuch as quinone is a strong oxidizing substance and potash salts are known from a previous research[6] to be retarders of root oxidation, analogous to the opposite effect of vanillin, a reducing substance overcome by nitrate known to stimulate root oxidation.

The green weights obtained at the end of the experiment bear out this observation. The relative growth in the quinone set was 75 per cent of the normal. The chief interest, however, centers

[6] Schreiner, O., and Reed, H. S., The rôle of oxidation in soil fertility. Bull. 56, Bureau of Soils, U.S. Dept. Agr. 1909.

in the comparative results obtained in the cultures containing 50 per cent and more of the phosphate, nitrate, and potash, respectively, in order to see which of these was the most efficient in antagonizing the action of quinone. The results of the grouping of cultures on this basis, made as explained in the preceding experiment, is shown in fig. 4. The mainly phosphatic fertilizer combinations show a relative green weight of 77 per cent of the normal,

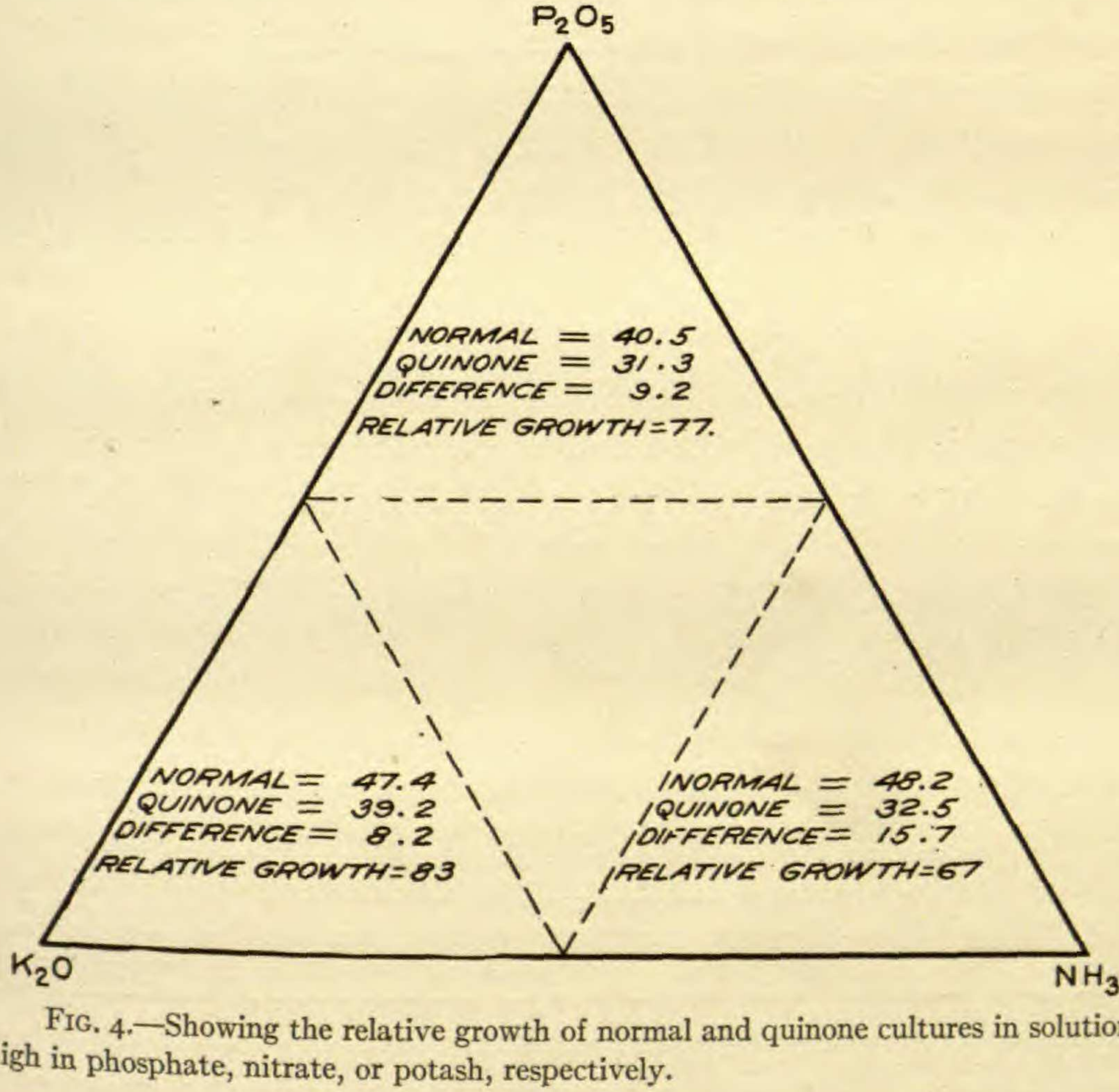

FIG. 4.—Showing the relative growth of normal and quinone cultures in solutions high in phosphate, nitrate, or potash, respectively.

the mainly nitrogenous 67, and the mainly potassic 83. It is observed that the potash fertilizers were the most efficient in overcoming the harmful effect of quinone.

This experiment with quinone was repeated, and this time the solutions were analyzed as in the case of the cumarin experiment. This second quinone experiment lasted from April 8 to April 20. It showed the same general slender appearance of the plants, as well as again showing the influence of the potassium fertilizers as above described. In this experiment the green weight in the quinone set as a whole was 79 per cent of that in the normal. The results for the mainly phosphatic, mainly nitrogenous, and mainly potassic fertilizers are 76, 77, and 85, respectively, again showing the relative greater efficiency of the potash fertilizers in this quinone experiment.

These quinone experiments indicate clearly the harmful influence of quinone on growth, and the effect of potassium in counteracting this action of the quinone. In the second experiment the cultures were analyzed for phosphate, nitrate, and potassium, and it is, therefore, interesting to inspect these data, as was done with the cumarin results. Only the 36 cultures having the combinations of all three fertilizer salts are considered.

The amount of total $P_2O_5+NH_3+K_2O$ removed from solution by the growing plants in the total number of 36 cultures was 1568 milligrams in the normal set and 1327 milligrams in the quinone set, showing a decrease in the sum total of P_2O_5, NH_3, and K_2O removed when quinone is present. In table III are given the results for the P_2O_5, NH_3, and K_2O separately under the normal conditions and in the quinone set.

TABLE III

TOTAL MILLIGRAMS OF P_2O_5, NH_3, AND K_2O REMOVED FROM THE 36 CULTURE SOLUTIONS CONTAINING ALL THREE OF THESE INGREDIENTS

	Total absorption in milligrams		Relative	Percentage of quinone cultures above normal
	Normal	Quinone		
P_2O_5	300.4	173.6	58	8
NH_3	571.5	506.8	89	11
K_2O	696.5	646.5	93	36

An inspection of these figures indicates strongly that the potassium absorption in the presence of quinone has been more normal than the other two nutrient elements. This is shown both by the relative absorption in the third column and by the number of quinone cultures showing normal or greater absorption of P_2O_5, NH_3, and K_2O, respectively, in the last column.

We have, therefore, the interesting case of a toxic oxidizing body being overcome by a fertilizer salt having a restraining action on the normal oxidative power of the root, accompanied by a relatively greater absorption of this fertilizer element than under normal conditions.

Discussion and summary

In the foregoing experiments with cumarin, vanillin, and quinone, the effects of these toxic substances on the development of wheat seedlings was demonstrable by three criteria:

1. By decreased green weight.

2. By the morphological effects as shown by their general appearance. Cumarin-affected plants have characteristic stunted tops, broad, distorted leaves; vanillin-affected plants are less characteristic, but show decreased growth of top and strongly inhibited root growth; quinone-affected plants are tall and slender, with thin, narrow leaves, in strong contrast to the cumarin-affected plants. The substances show, therefore, a markedly different behavior in detail, although all show a toxic effect in inhibiting growth.

3. By decreased absorption of plant nutrients. The cumarin depressed potash and nitrate removal from nutrient solution more than phosphate; the quinone, on the other hand, depressed phosphate and nitrate more than potash; the effect of vanillin was not determined in this regard. It might be interesting to mention, however, that dihydroxystearic acid, which appears to act much as vanillin did, depressed phosphate, and potash more than nitrate. In this respect again the influence of the various harmful substances was different.

The various fertilizer salts acted differently in overcoming the respective harmful effects of these toxic compounds. The mainly phosphatic fertilizers were the most efficient in overcoming the cumarin effects; the mainly nitrogenous fertilizers in overcoming the vanillin effects; the mainly potassic in overcoming the quinone effects.

This different action of fertilizer salts on the toxic compounds is also illustrated by the diagrammatic representations in fig. 5 of the regions of greatest growth obtained in the various experiments. The triangle represents the various cultures containing the fertilizer combinations, as is fully explained in fig. 1 and the accompanying text.

Under normal conditions, that is, without any toxic body present, the greatest growth is found in those cultures low in phosphate and about halfway between the nitrate and potash angles. This

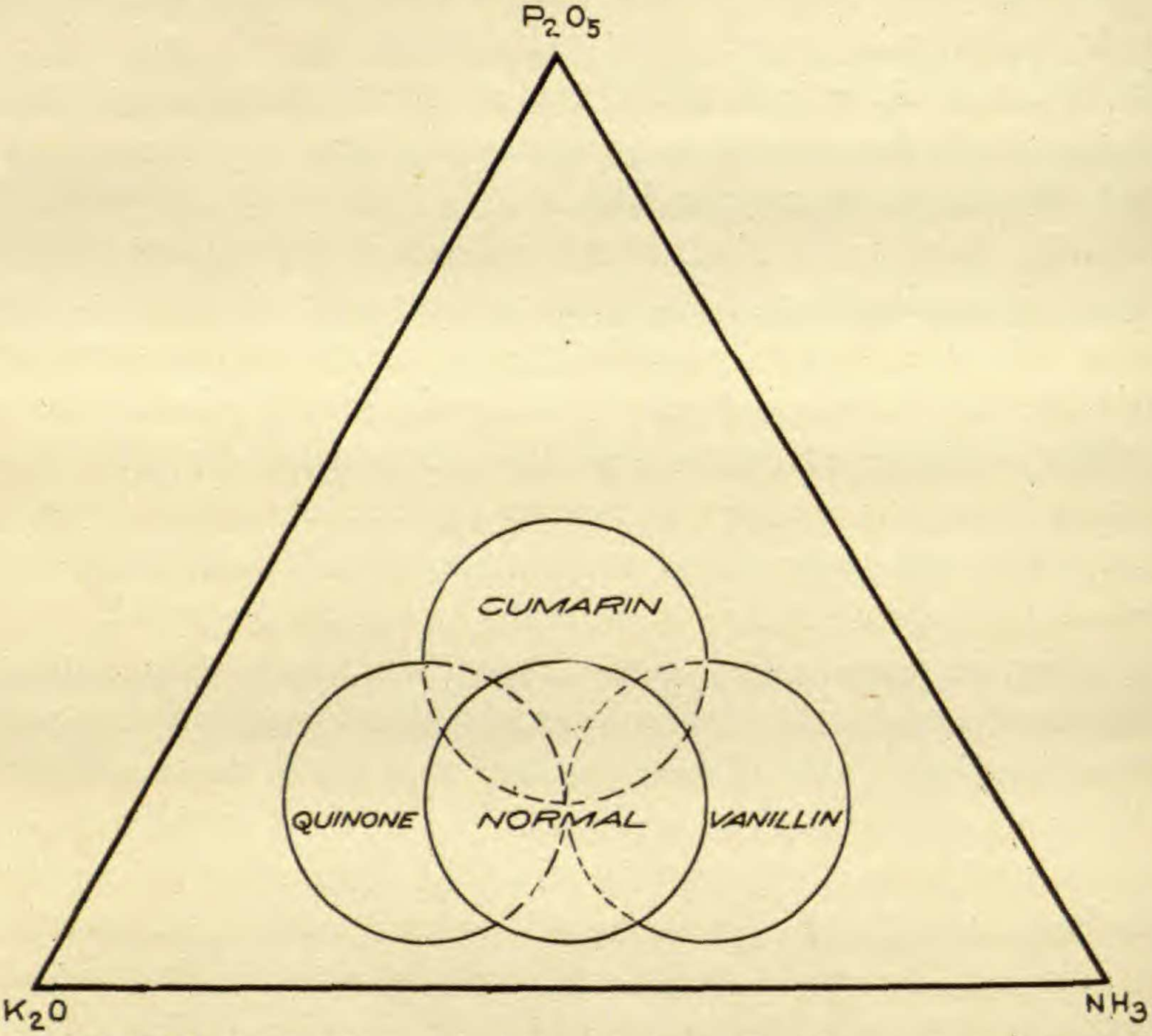

FIG. 5.—Diagrammatic representation of the region of greatest growth in the triangle culture experiments with cumarin, vanillin, and quinone.

region of greatest growth is diagrammatically represented by the circle marked normal in fig. 5. When cumarin is present in the cultures, the effect was to cause the region of greatest growth to shift in the direction of the phosphate angle, a condition which may be diagrammatically shown by the circle marked cumarin. With quinone, this region of growth was shifted toward the potash angle, and with vanillin toward the nitrate angle, as illustrated in the diagram.

This shifting of the region of greatest growth was accompanied by a corresponding change in the absorption of plant nutrients, although this is not as marked as the green weight. All of these facts are in harmony with the conclusion drawn from the data already given, that phosphate fertilizers were antagonistic to cumarin, that potash fertilizers were antagonistic to quinone, and that nitrate fertilizers were antagonistic to vanillin and to dihydroxystearic acid.

In regard to the exact mechanism of the chemical or physiological character of the interactions between these toxic substances and the fertilizer salts, nothing definite can be said. Attention, however, should be called in this connection to the fact that the reducing poisons vanillin and dihydroxystearic acid are antagonized by those fertilizer combinations which stimulate oxidation, and that the oxidizing poison quinone is antagonized by the fertilizer combinations checking oxidation, thus indicating that there is some correlation between these functions. A discussion of the interaction of cumarin and phosphate fertilizers would be mere speculation in the present state of our knowledge.

Attention must also be called again to the fact that the observations here recorded for phosphate, nitrate, and potash were obtained with the salts, calcium acid phosphate, sodium nitrate, and potassium sulphate, and that the observed results, therefore, may be caused by these substances as a whole, that is, as combinations rather than individual elements. For deciding this question, further investigation is necessary, involving experiments with other salts and combinations.

These actions of the different fertilizer combinations or different fertilizer requirements, as they may be styled, show a certain parallelism with field observations on soils and their fertilizer requirements, and one is tempted to ask to what extent may the different fertilizer requirements of different soils or of the same soil under different conditions be influenced by the same cause. That harmful bodies occur in soils has been amply shown, and that these are influenced directly or indirectly by fertilizer salts is also clear from this and other researches. That the constitution of the organic matter varies from soil to soil, and in the same soil under different conditions of aeration, drainage, and cropping, is likewise clear. The presence of compounds inimical to plant growth by virtue of a property resembling that of any of the above-mentioned poisons might therefore cause a different fertilizer requirement, a requirement which might even change from time to time according to the nature of the biochemical reactions producing the body, or according to the nature of the plant remains in the soil; in other words, according to rotation, with its necessary altered soil management, and the altered biochemical changes produced in the different plant remains.

The action of fertilizers on soils is a much contested question, but the weight of evidence is against the assumption that their effect is due altogether to the added plant food. If so simple an explanation were the true one, nearly a century of investigation of this problem by scientists of all civilized nations would surely have produced greater unanimity of opinion than now exists in regard to fertilization. Thoughtful investigators everywhere are finding that fertilizer salts are influencing many factors which contribute toward plant production besides the direct nutrient factor for the plant. It is this additional influence of fertilizers which makes them doubly effective when rightly used and inefficient when improperly used. To this influence of fertilizers on soil and biological conditions is due their capriciousness when applied on the theory of lacking plant food, and any study which throws further light upon the mooted question is of direct help toward reaching that view of soil fertility and soil fertilization which will eventually result in a more definite system of fertilizer practice, to the end that surer and safer returns are obtained from their use. This will tend to extend fertilizer practice by making it more remunerative and rational than in the past.

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